NATIONAL ADVANCED DRIVING SIMULATOR SYSTEM ARCHITECTURE

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ABSTRACT

The National Advanced Driving Simulator (NADS) system was designed to conduct driver centered safety studies. The NADS contains three major components: the Software Engineering Environment (SEE), the Simulation Development Module (SDM), and the main NADS (the real-time simulator. The purpose of the SEE is to provide an environment for development of the NADS software, databases, and scenarios. The purpose of the SDM is to validate scenarios before actual execution on the NADS. The full NADS contains all of the capabilities required for driver centered research using the general population, including a state of the art Scenario Definition and Control capability.

INTRODUCTION

The National Advanced Driving Simulator (NADS) is a very high fidelity driving simulation environment designed to conduct fundamental research into the operation of the complex driver-vehicle-environment system. It was designed and developed for the National Highway Traffic Safety Administration (NHTSA) and is operated by the University of Iowa. The system is installed in a dedicated, purpose-built facility at the Oakdale Research Park complex of the University of Iowa.

The NADS is being used to study various factors that affect the general driving population who are involved in almost 6.8 million police reported vehicle motor vehicle collisions annually. The NADS is uniquely suited to conduct this collision avoidance research. Participants from the general population are not only immersed in a rich driving scene, fully engrossing them in the driving task, but, in situations where crashes might normally occur, they can be involved without danger. The obvious advantage is that the identical situation can be reconstructed for as many participants as necessary to fully understand the factors involved in the hypothetical, but realistic situation. The NADS also provides the capacity for safely evaluating the effects of emerging technologies in advanced vehicle communication, navigation and control as well as evaluating highway engineering and design approaches as they relate to traffic safety.

Since NADS was designed to test the driving behavior of the general driving population, two key design issues for NADS were (1) mitigating motion sickness – also known as Simulator Adaptation Syndrome (SAS) and (2) assuring participant safety. SAS mitigation was achieved using the large motion envelope to improve washout capability and very tight requirements on cue realism and correlation. To accomplish the necessary cue realism, motion, visual and audio subsystems were required to generate high fidelity cues, correlated to within 28 milliseconds. This required realism drove the NADS design to develop a realistic vehicle cab environment, the best available virtual visual and aural environment, and of course the computer processing power to keep all aspects synchronized during the simulation.

Safety was designed into the NADS from the beginning. The NADS contains a comprehensive Emergency Stop capability that can be enacted manually or automatically. It has many facility related physical interlocks (e.g., doors into the motion bay), and activation buttons at critical locations - including in-cab. Safety of the simulation "driver" and support technicians was of paramount importance in all aspects of the NADS.

The NADS was developed, integrated, and installed by the TRW NADS Team comprised of TRW of Reston, VA, MTS Systems of Eden Prairie, MN, Evans & Sutherland (E&S) of Salt Lake City, UT, Dynamics Research Inc. (DRI) of Torrance, CA, I*SIM of Salt Lake City, UT, AERCOL of Toronto, Canada, and the University of Iowa (UoI).

- As prime contractor, TRW was responsible for systems engineering and integration and also developed the Operator Station, Researcher Interface Module (RIM). TRW was also responsible for overall simulator control and safety monitoring, and data collection.
- MTS Systems developed the complete NADS Motion Subsystem.

- Evans & Sutherland provided the computer-generated graphics, simulation and real-time visual image generation, projection system and the dome.
- Dynamic Research Inc. supplied the four cab subsystems, including the control feel, and vehicle dynamics software support.
- I*SIM developed the NADS Audio.
- The University of Iowa provided the majority of the Scenario Definition and Control software as well as contributed the baseline vehicle dynamics (NADSdyna).
- AERCOL provided MTS Systems with technical services on Motion System control and motion prediction simulation software.

SYSTEM OVERVIEW

The NADS system entails three separate support capabilities as depicted in Figure 1:
- Software Engineering Environment (SEE): Supports Researchers in developing scenarios and experiments and maintaining system software and databases.
- Simulation Development Module (SDM): Supports Researchers in validating the scenarios and experiments to ensure they will run on the main NADS Environment and will satisfy the desired research goals.
- NADS: Supports Researchers in running experiments and data gathering on the main NADS Environment. (Throughout this paper, the term "NADS" refers to the full capability system with motion. The term "SDM" refers to the medium fidelity, fixed base validation system.)

Software Engineering Environment

The SEE comprises a variety of hardware and software throughout the NADS Facility. At its heart is the SEE Server and the main NADS data repository, which contains simulation scenarios, configured source and executable software, experiment data, etc.

The SEE Workstations also contain the primary software tools to develop and rehearse scenarios and experiments. These tools include the tools to:
- Develop sophisticated visual scenes for the scenarios along with the associated roadway description data:
  - Including modifying existing databases / database components (tiles) or building new ones,
  - Providing an ability to "mosaic" the visual scene components into larger components / databases, using the "Tile Mosaic Tool"
- Generate the visual scene database for direct use on the Image Generator, using IG supplied tools
- Generate a concatenated roadway definition using the Logical Roadway Information (LRI) Generation tools. The LRI contains all of the information needed to define and control realistic traffic patterns around the participant's vehicle.
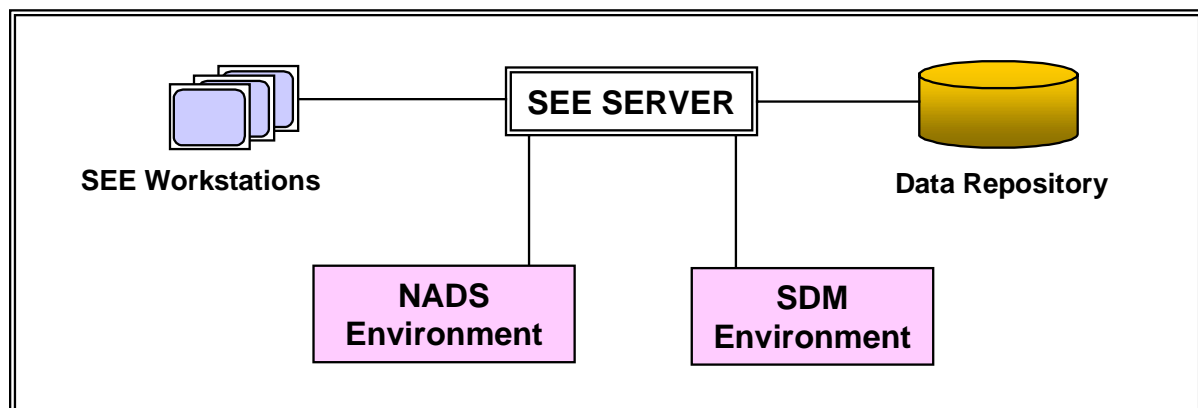

Figure 1. System Identification.

- Define / rehearse scenarios within the roadway network created by the visual scene and roadway generation, using the Interactive Scenario Authoring Tool (ISAT). Using the ISAT, the researcher can add a large number / variety of visual objects (ambient traffic, special traffic, pedestrians, road debris, etc.) and controls (traffic signals, signage, lighting, weather, etc.) to the visual scene. The scene is not "canned", but generated in real-time based on the scenario definition (roadway as well as other vehicles) and the driver's reactions.

SDM Environment

The SDM is a medium-fidelity fixed base simulator environment for scenario check-out and has a real-time computer environment, a fully functional NADS cab, a motion simulator (no real motion), a slightly lower resolution image generator with 120° screen projection, and all of the necessary control hardware and software to determine if the developed scenario will run properly prior to installation on the full motion NADS.

NADS Environment

The NADS Environment is the combination of computer hardware and software, mechanical and physical components that enable the realistic simulation environment presented to a participant driver. Figure 2 is representative of the major items within the NADS Environment.

As the Figure 2 shows, the NADS Environment is complex with the various subsystems, and important control and monitoring components. In order to provide a reasonable overview of the NADS, we will break it down to major components and provide information on the available functionality within them. The primary subsystems from the inside out as shown in Figure 2 are as follows:

a. Platform mounted **Cab Subsystem** with integrated **Audio Subsystem**,
b. **Visual Subsystem** Image Generator and dome mounted projector array,
c. **Motion Subsystem**, including control computers, networks, and X & Y-axis, full hexapod, and turntable control
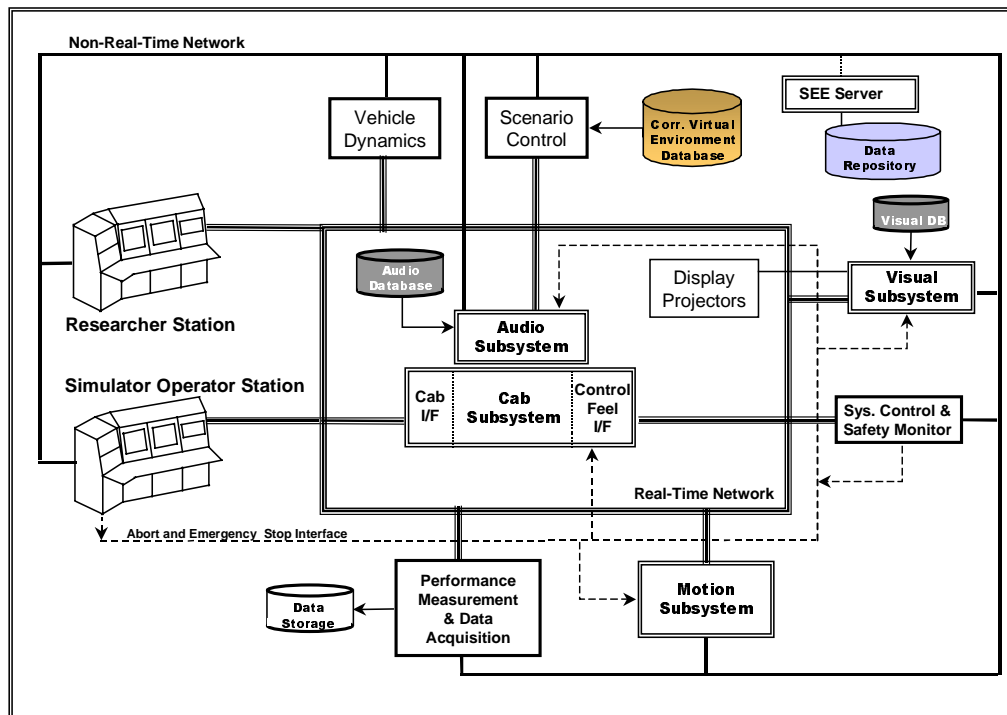

Figure 2. NADS Environment.

    d.   Simulator Monitor and Control (**SMAC**) **Subsystem**, includes the Stations, Vehicle Dynamics, System Control and Safety Monitor, Scenario Control, and Data Collection.

Cab Subsystem

The Cab Subsystem, supplied by DRI, consists of actual vehicle cabs that are modified for NADS to interface with the computer controlled NADS simulation environment. They provide a realistic vehicle exterior and interior, driver action feedback, instrument indications and safety equipment. They are equipped with an entertainment system (AM/FM, CD player) and air conditioning system. They also contain CCTV cameras for driver monitoring and an intercom for voice contact with the NADS Simulator Operator or Researcher. The four types of cabs presently available for driving simulations are as follows:
1. 1996 Ford Taurus
2. 1997 Jeep Cherokee
3. 1997 Chevrolet Malibu
4. 1998 Freightliner FLD120, Class 8 Heavy Truck

Audio Subsystem

The Audio Subsystem, supplied by ISIM, generates the cab internal and external road and drive train noises associated with driving. The Audio Subsystem also provides the necessary external audio sounds from other vehicles and objects in the simulation. This is accomplished with a PC type computer that contains a vast library of audio files that are selected as the simulation progresses and played through the Audio Subsystem speakers of the cab. The subsystem is a high fidelity, high power 13-channel sound system with a focal point aimed at the driver such that the optimal sound pressure is achieved at the driver's head.

Visual Subsystem

The Visual Subsystem, provided by E&S, consists primarily of the 15 channel Harmony® Image Generator (IG) and the dome mounted projector array. This powerful IG generates the real-time visual scene presented to the simulation driver by the fifteen-projector array in response to driver inputs. It provides a seamless 360° image with a high resolution inset in the driver's directed field-of-view. The generated scene is projected onto the interior dome surface, which has been especially coated to provide a bright and high-contrast image focused at the simulation driver.

Motion Subsystem

The Motion Subsystem, developed by MTS, is composed of the large scale X and Y components, which provide a maximum ± 32 feet of travel. Longer motion excursions can be achieved using the combined X and Y motion along a diagonal. In addition to the X and Y axis, the Z axis has ± 2 feet of vertical travel and the motion Platform rotates ± 330°. To provide a realistic "road feel", the Motion Subsystem also has four self-reacting Vibration Actuators which are rigidly mounted to the Platform and provide ± 0.2 inches of vertical high-frequency (<25Hz) force to the cab at the wheel wells. Adaptive washout algorithms translate driver head point specific forces and angular velocities into appropriate X, Y, Z, and hexapod commands to provide the sensation of accelerations and "turns".

SMAC Subsystem

The Simulator Monitor and Control Subsystem (SMAC) developed and integrated by TRW, is the heart of the computational capability for the NADS. It is the central command and control for the NADS. The SMAC provides the Simulator Operator and Researcher with the capability to control and monitor the other Subsystems. Once an experiment is started, the control software ensures a safe and successful completion of the experiment while collecting the necessary data for real-time and off-line detailed analysis. The subsystem, consisting of a distributed real-time computer architecture, also contains the following key components:
    a.   A separate System Control and Safety Monitoring computer,
    b.   Scenario Control software,
    c.   Vehicle Dynamics software,
    d.   Simulator Operator and Researcher Interface Stations,
    e.   Separate Data Acquisition computer and storage

Figure 3 shows the distributed nature of the computer processing for the NADS. The distributed computer architecture employs high-speed embedded computers, data buses, and shared memory to perform the computations and data exchange necessary for real-time simulation. This approach provides modularity, upward growth capacity, and a minimization of signal delays which impact transport delay, spatial, temporal, and cue phase correlation.
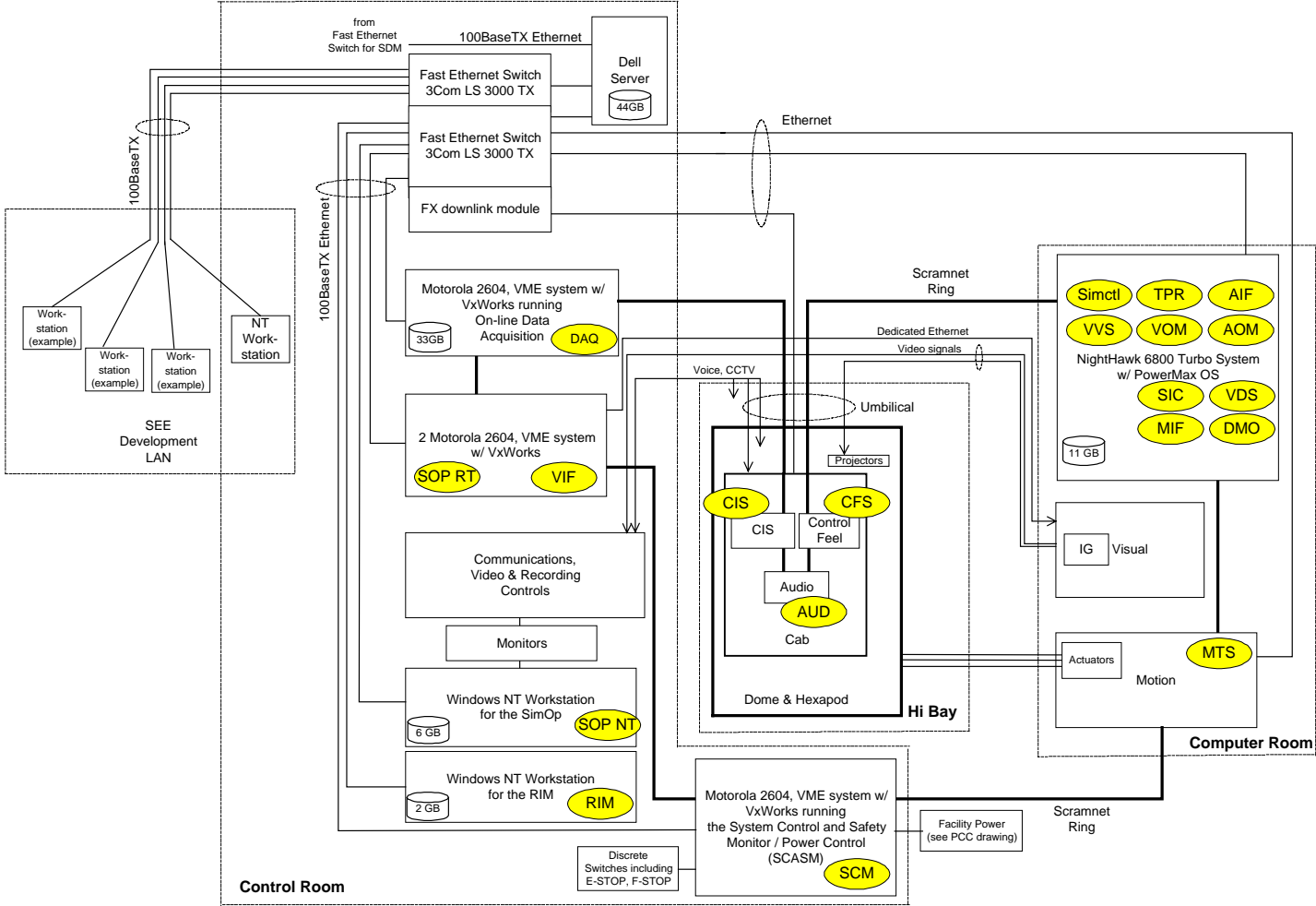
Figure 3. NADS Architecture.

The SCASM

The System Control and Safety Monitor (SCASM) controls system states and monitors subsystem status. In the event of data communication loss or corruption, potential violent maneuvers or system motion, the SCASM software and hardware initiate a safe system shutdown by commanding all subsystems to stop, and turning off power to the Motion Subsystem.

The DAQ

Data collection on the NADS includes two types: (1) the collection of "raw" data from the real-time network and (2) the visual/audio recording of participant activities while driving. These data can be correlated via the simulation "frame number" as well as the "time stamp" of the recorded information.

In addition to these two information sources that are generally reviewed and analyzed after simulation runs, NADS supports real-time display of a limited number of simulation variables during a run. This is accomplished by tapping into the raw data collected via the DAQ, and processing it through a charting tool at the Researcher and/or SimOp Station(s). Thus, for example, driver response trends can be seen during the simulation without affecting performance.

The raw data collected can be processed and analyzed by the Researcher immediately after a run, or saved for future/further analysis. The NADS supports immediate processing of the raw data into a MATLAB format. Then, using MATLAB (available on the SEE Workstation that is located at the Researcher Station), the Researcher can perform any desired analysis supported by that tool.

Initially, Data Acquisition is specified during the Scenario Development phase as part of the scenario. In addition, the Simulator Operator, Researcher and Scenario Control on the Concurrent may modify this collection set during the simulation execution. This capability to change the data collection rates and variables dynamically from Scenario Control permits increasing and decreasing the amount of data based on driver actions or specific scripted events.

The Control Stations

The Simulator Operator (SimOp) and Researcher Stations have been designed with different objectives in mind:

- The SimOp Station is designed to control and monitor the entire NADS. Its emphasis is the safe and controlled running of a very sophisticated computer controlled machine.
- The RIM Station, on the other hand, is designed to permit the Researcher to see and carefully monitor the progress of the simulation via CCTV and generated image screens. The RIM Station is also the focal point for experiment data collection and spontaneous "injection" of events, which permute the driving environment. The RIM Station has no control over the execution of a simulation, that is the sole domain of the SimOp Station.

The Simulator Operator and Researcher Stations include multiple screen display monitors that can be used to present video or digital data through split-screen windowing. Headphones and speakers allow direct communication with the participant and in-cab assistants while additional video monitors on the RIM Station present the visual scenes as seen by the driver.

The Simulator Operator has additional safety controls to power-up the NADS, move it under Operator control, power it down or initiate an emergency stop. The SDM incorporates both Simulator Operator and Research Interface Stations into one SDM station by eliminating most of the viewing screens. System data security is provided through multi-level access control and physical separation.

Scenario Development

The Researcher will determine what type of virtual environment is required for an Experiment and then can use the NADS capabilities to build that environment (see Figure 4). The researcher typically would review existing virtual environments and determine if any of them are suitable, with minor or major modifications for the new experiment. If none of the existing environments are suitable, a new virtual environment could be created.

Scenario Development is available through workstations in an environment utilizing a Graphical User Interface (GUI) supported by table-driven menus to enhance flexibility and understanding. The primary tool available for this capability is the Interactive Scenario Authoring Tool (ISAT), which is available on any NT-based Workstation.

Driving scenarios are only limited by the imagination and are generally a joint effort between Researchers and the University of Iowa Simulator staff. Researchers usually contact and develop driving scenarios in advance before any tests are ever conducted. The NADS simulator contains tools to create a variety of virtual worlds and driving experiences to conduct testing of a variety of complex driving situations.

1. *Minor modifications to an existing scene* - Making minor modifications to a scene typically consists altering the traffic light sequence, traffic density and traffic behavioral changes. This is accomplished using the Interactive Scenario Authoring Tool and permits rapid Scenario/Experiment development.

2. *Major modifications to an existing scene* - Making major modifications to a existing scene entails altering the placement of existing tiles (parts of a virtual world) with the Tile Mosaic Tool (TMT). A new Logical Roadway Information (LRI) file is then generated before finishing the scenario development process with ISAT.

3. *Generate New Scene* - Creating an entirely new scene is a laborious and expensive process that entails using the visual scene and model development workstation with sophisticated graphics development tools such as MultiGen Road Tools. Once new models and/or tiles are created, a new Open Flight database must be

generated. Then the Project Engineer uses the TMT to include the newly created virtual world parts into the Visual Database. After generating the new LRI, ISAT is used to complete the scenario development process.

Interactive Scenario Authoring Tool

The Interactive Scenario Authoring Tool (ISAT) is a powerful tool for the graphical authoring and testing of driver simulation scenarios (see Figure 5). The ISAT gives the Researcher various levels of control in scenario development. At the highest level, patterns and density of ambient traffic can be set, as well as driver visibility and time of day. At the other extreme, a Researcher could create specific traffic situations, specifying when each vehicle appears, along with its path, speed and model. As the scenario is developed, the ISAT can be used in its testing. The ISAT runs the scenario, in Rehearsal mode, using the same behaviors software as the actual driving simulator. The ISAT can be used to monitor the scenario's progress, and to issue some commands. The ISAT's Monitor mode displays a top-down view of the actual simulation and enables the user to select vehicles for control, setting their speed and travel path. Figure 5 shows the top-level graphical user interface for the ISAT. From here, the user selects the various capabilities of the ISAT via ICONS, drop-down menus or item selections and dialog boxes.
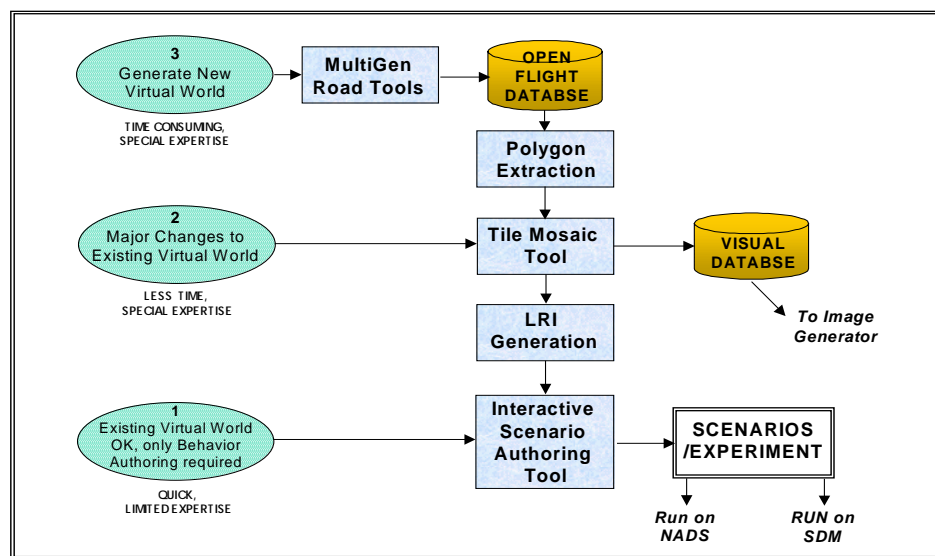.

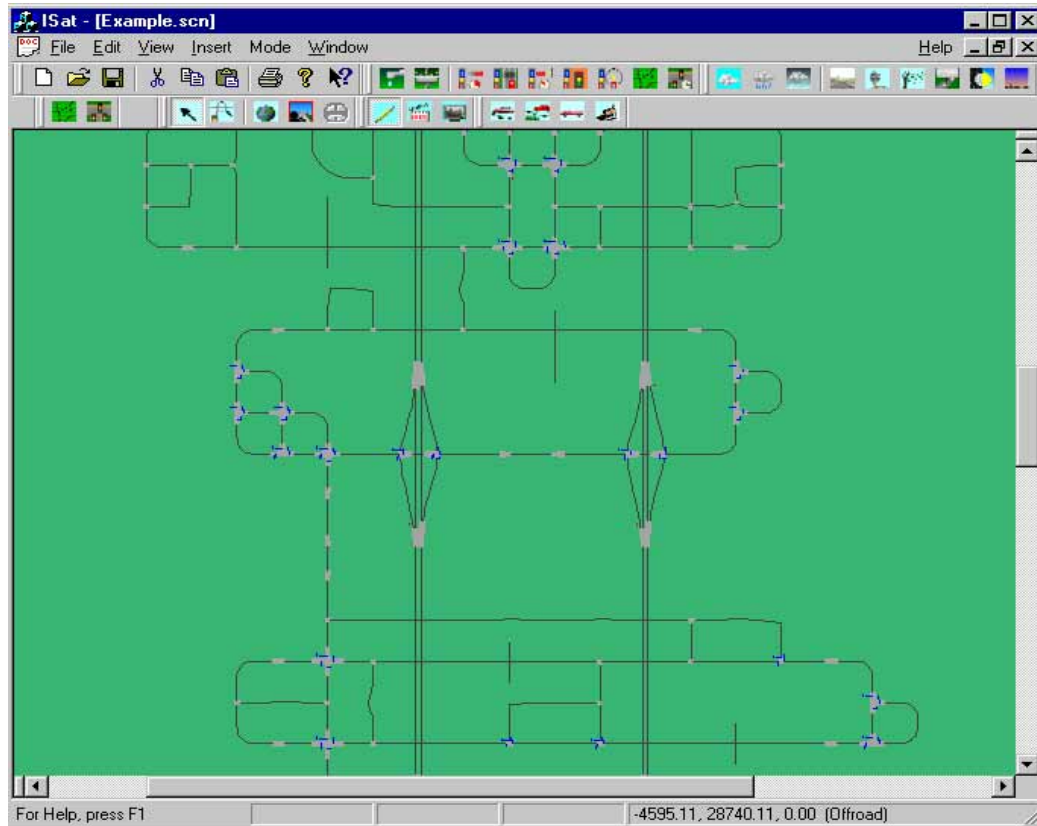**Figure 4. Selecting a Virtual Environment for an Experiment.**

Figure 5. ISAT Graphical User Interface – Top Level.

Summary of NADS Performance

The basic performance parameters for the NADS are as follows:
Motion: The motion envelope is ± 32 feet in X and Y, with ± 2 feet in Z and ± 330 degrees of yaw. This unprecedented motion range can be traversed at a velocity of 20 ft/sec with an acceleration up to of 20 ft/sec^2
Visual: The virtual driving world is a state-of-the-art image generator projected onto a 360° reflective dome.
Cabs: The NADS cabs are real vehicles, which are encountered on the roads of America every day. Their interiors appear virtually the same as an OEM vehicle with all controls and displays functional. The cab sound generation system with 13 separate channels provides all audio cues for the cab driver.
Response / Latencies: System response is less than 80 milliseconds from stimulation to cue presentation, with correlation of cues within 28 milliseconds